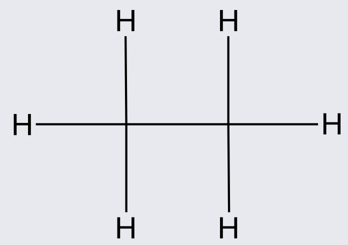
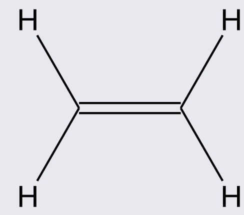
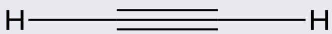
BONDING – SL/HL – NETWORK/METALLIC HL TOPICS HYBRID ORBITALS

IB Chemistry

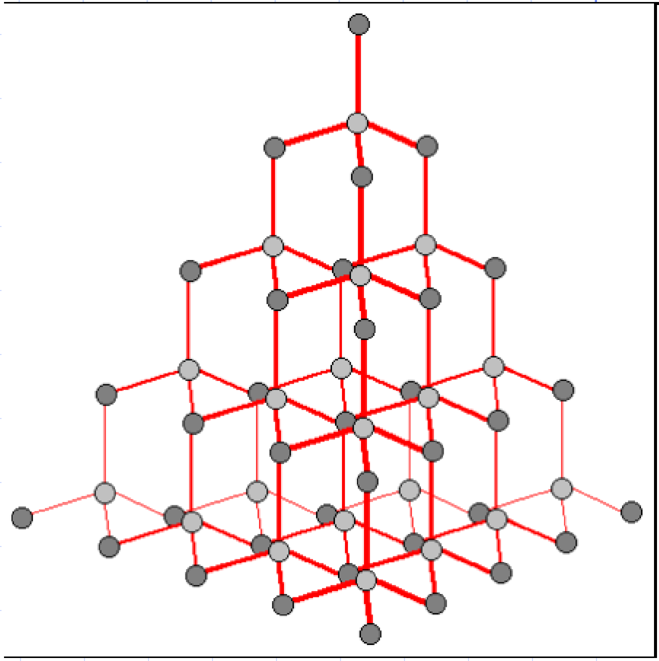
Topic 04 - Bonding

Bond Type Properties

Hydrocarbon	C_2H_6 **Ethane**	C_2H_4 **Ethene**	C_2H_2 **Ethyne**
Structural Formula			
Type of bond between carbons	Single	Double	Triple
Bond length (nm)	0.154	0.134	0.120
Bond enthalpy (kJ/mol)	347	612	838

Covalent Network Solids

- Network solids have repeating network of Covalent bonds that extends throughout the solid forming the equivalent of one enormous molecule.
- Such solids are hard and rigid and have high melting points.
- Diamond is the most well-known example of a network solid. It consists of repeating tetrahedrally bonded carbon atoms.

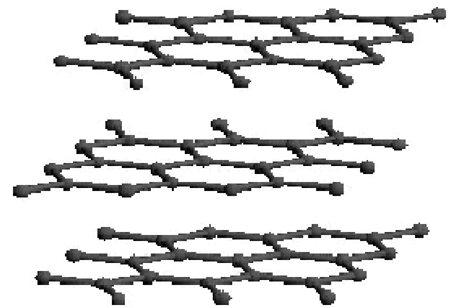


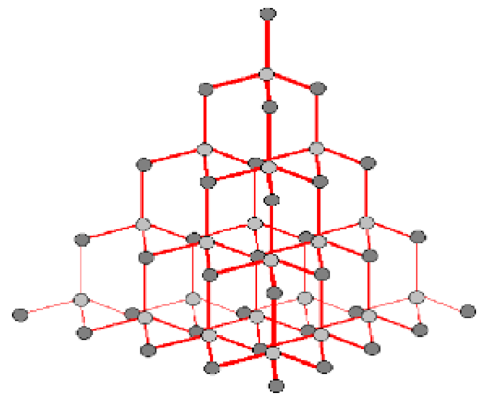
Network structure for diamond

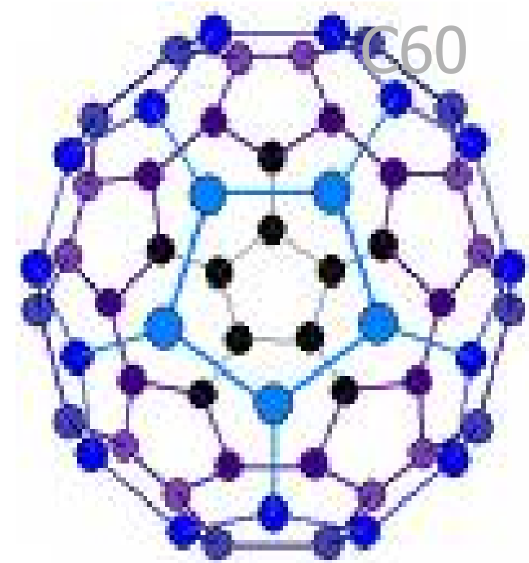
Allotropes

- Carbon actually has several different molecular structures.

- These very different chemical structures of the same element are known as allotropes.
- Oxygen, sulfur, and phosphorous all have multiple molecular structures.







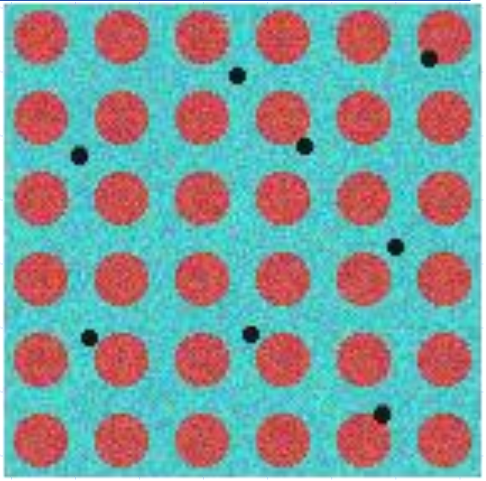
Metallic Bonding

Metallic Bonding

Metallic Bonds are a special type of bonding that occurs only in metals

A metallic bond occurs in metals. A metal consists of positive ions surrounded by a "sea" of mobile electrons.

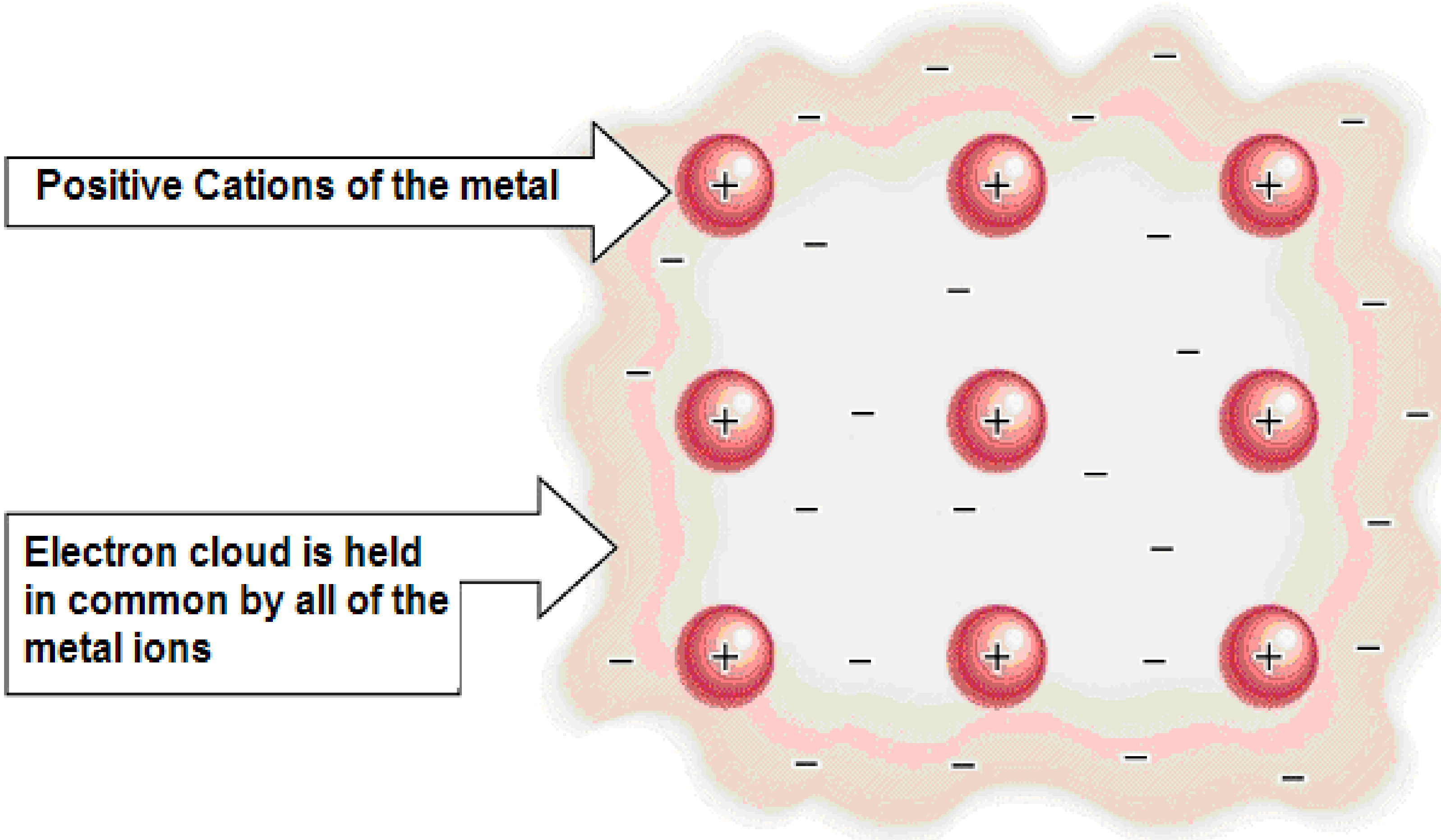
This diagram shows how metallic bonds might appear



Characteristics of a Metallic Bond.

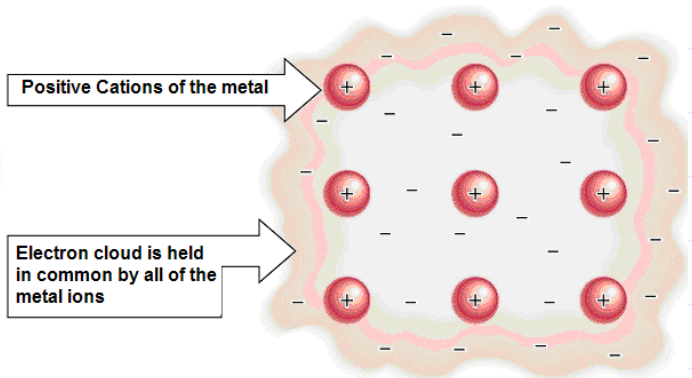
1. **Good conductors of heat and electricity**
2. **Great strength**
3. **Malleable and Ductile**
4. **Luster**

Metallic Bonding

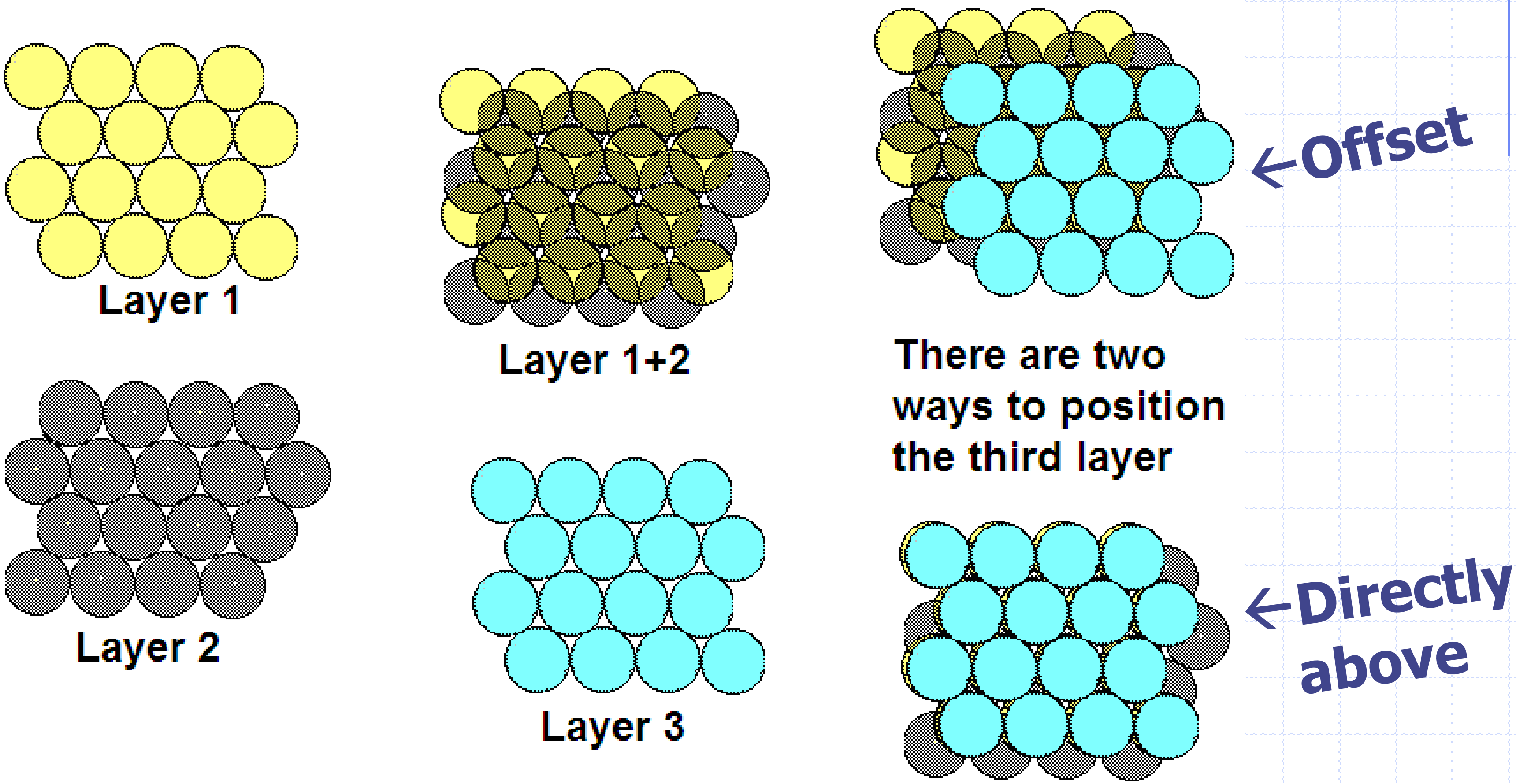


Metallic Bonding

- **All the atoms in metallic bonds are alike. They all have diffuse electron densities. They are similar to the cations in ionic bonds.**
- **Like the cation in ionic crystals, metallic atoms give up their valence electrons, but instead of giving the electrons to some other specific atom, they are redistributed to all, and are shared by all.**
- **The model is called "electron gas".**
- **Eg. Na metal. $1s^2 2s^2 2p^6 3s^1$. Each Na atom gives up its $3s^1$ electrons. We end up with an array of positive ions in a sea of negatively charged space.**
- **The electron gas behaves like the glue.**



Close Packing Structures



There are two ways to position the third layer: Offset and directly above layer 1

Metallic Bond Characteristics

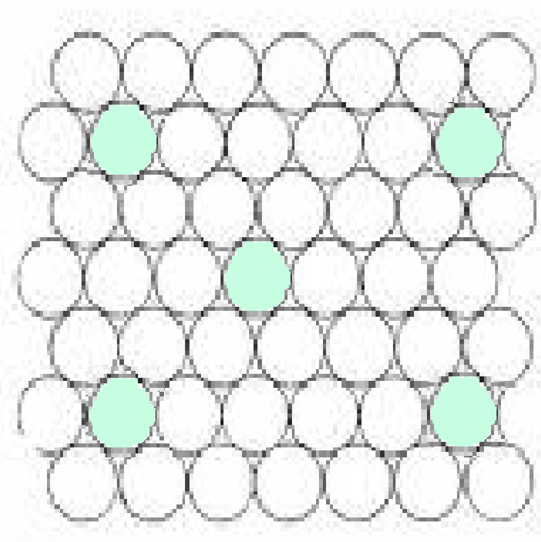
- Properties of metals
  - Metallic shiny luster.
  - Malleable.
  - Electrical conductivity.
  - Easy tendency to form alloys.
  - High density.

- Alloys
  - Because the atoms are considered to be positive spheres in a sea of electrons , any similar sized sphere can fit right in without too much trouble.
  - Even dissimilar sized (i.e. even smaller H atoms) can fit into the spaces between atoms.

Alloys

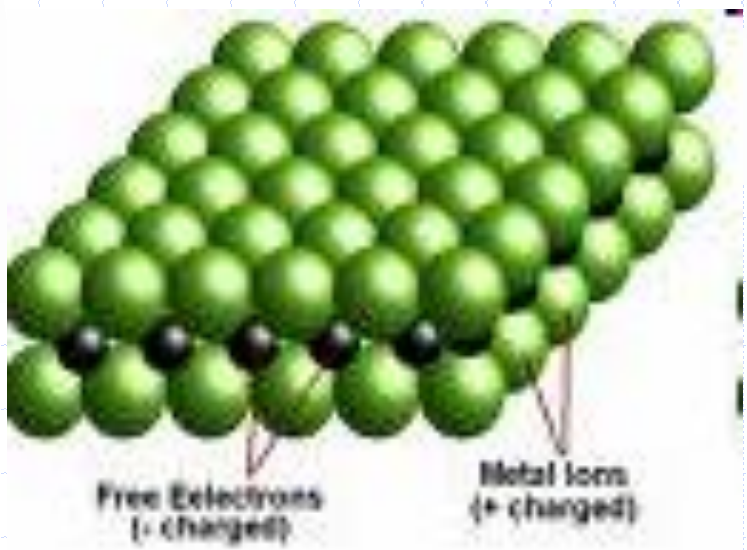
- Small amounts of a another element added to a metal can change its overall properties.

- For example, adding a small amount of carbon to iron, will significantly increase its hardness and strength forming steel.



Semimetals

- The electrons in semimetals are much less mobile than in metals, hence they are semiconductors

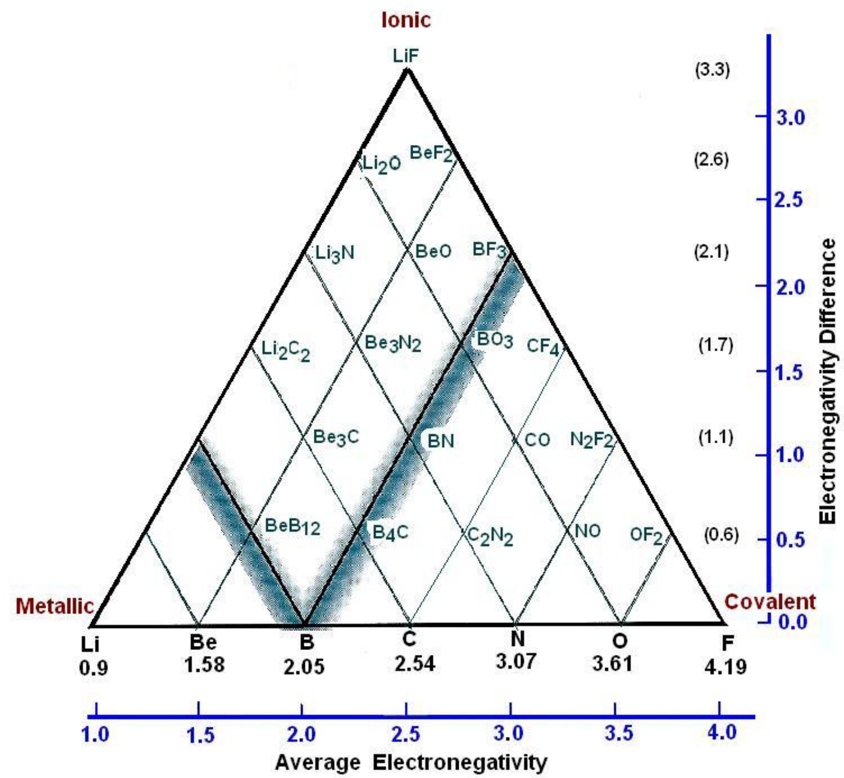


Comparison of Types of Bonding

	Ionic	Covalent	Metallic
Formation	Anion & cation Transferred electrons	Shared electrons	Cations in a sea of mobile valence
Source	Metal + nonmetal	Two nonmetals	Metals only
Melting point	Relatively high	Relatively low	Generally high
Solubility	Dissolve best in water and polar solutions	Dissolve best in non-polar solvents	Generally do not dissolve
Conductivity	Water solutions conduct electricity	Solutions conduct electricity poorly or not at all	Conduct electricity well
Other properties	Strong crystal lattice	Weak crystal structure	Metallic properties; luster, malleability etc.

Bonding Types Are Continuous

- There are no clear boundaries between the three types of bonding.
- Chemical bonding may be thought of as a triangle.
- Each vertex represents one of the three types of chemical bonds.
- There are all degrees of bonding types between these extremes.

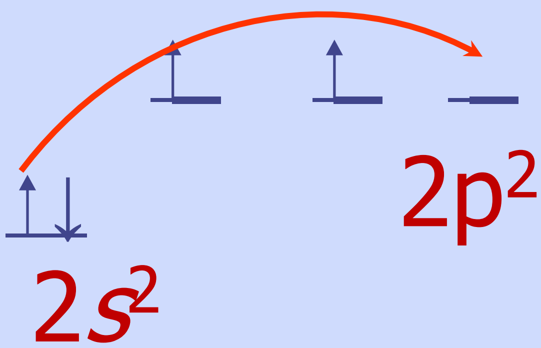


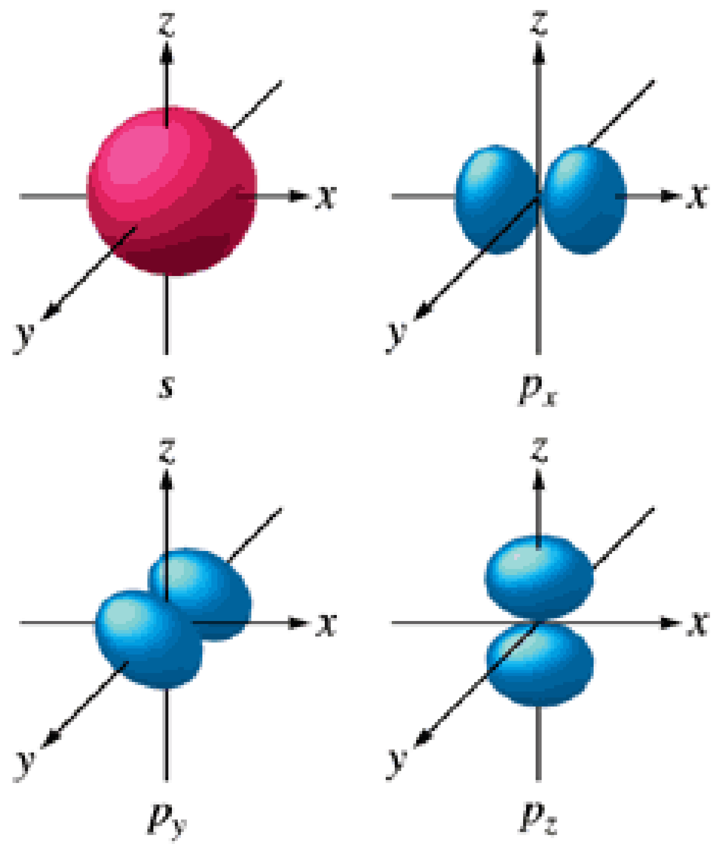
HL - Hybridization

Hybridization of Orbitals

- The merging of several atomic orbitals to form the same total number of hybrid orbitals.

Example: Unhybridized Outer Orbitals of Carbon





Why does carbon form four bonds with other atoms?

- This can be explained with the model of hybridization of orbitals.

- When atoms form bonds, their simple atomic orbitals often mix to form new orbitals called **hybrid orbitals**.

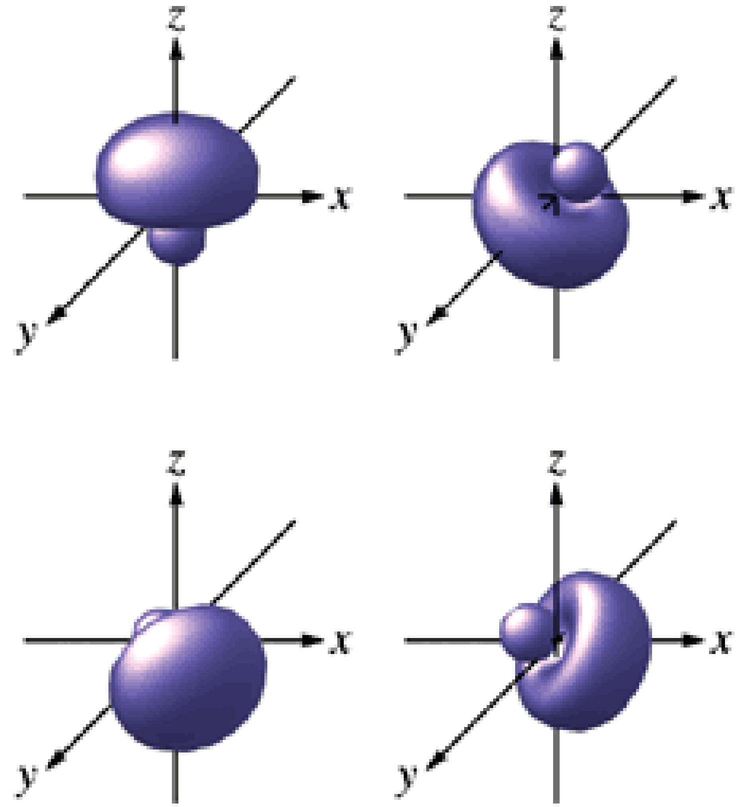
Hybridization: mixing of two or more atomic orbitals to form new hybrid orbitals

1. Mix at least 2 nonequivalent atomic orbitals (*e.g.* s and p). Hybrid orbitals have very different shapes from original atomic orbitals.
2. Number of hybrid orbitals is equal to number of pure atomic orbitals used in the hybridization process.
3. Covalent bonds are formed by:
   a. Overlap of hybrid orbitals with atomic orbitals
   b. Overlap of hybrid orbitals with other hybrid orbitals

Hybridized Orbitals of Carbon in forming Methane

- The **s** orbital merges with the three **p** orbitals to form four **sp^3** hybrid orbitals that are identical.

sp^3 **sp^3** **sp^3** **sp^3**



sp^3 Hybridization of C in CH_4

Unhybridized Carbon

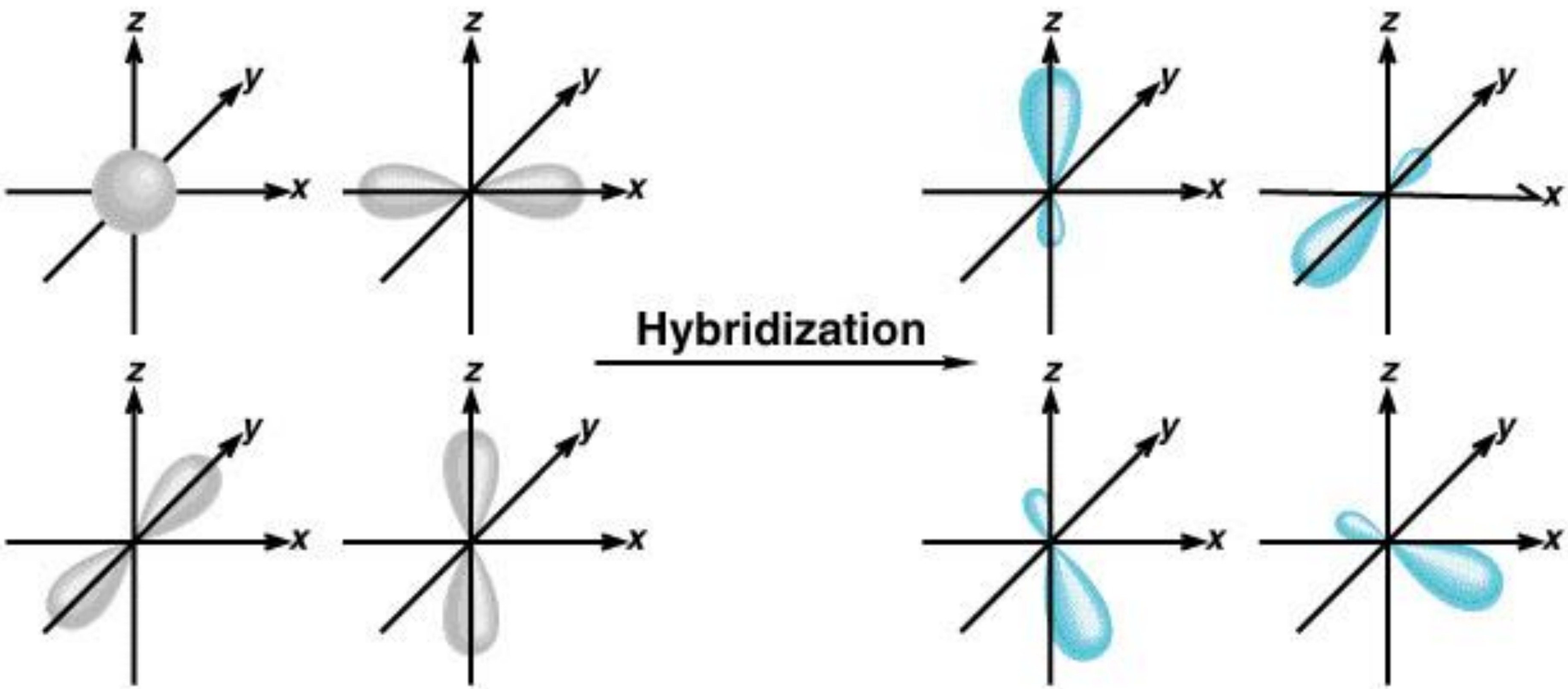
$2s^2$ $2p^2$

For CH_4, 4 hybrid orbitals are needed, so 4 atomic orbitals are required as follows: $(s + p + p+p) = sp^3$

Hybridized Carbon

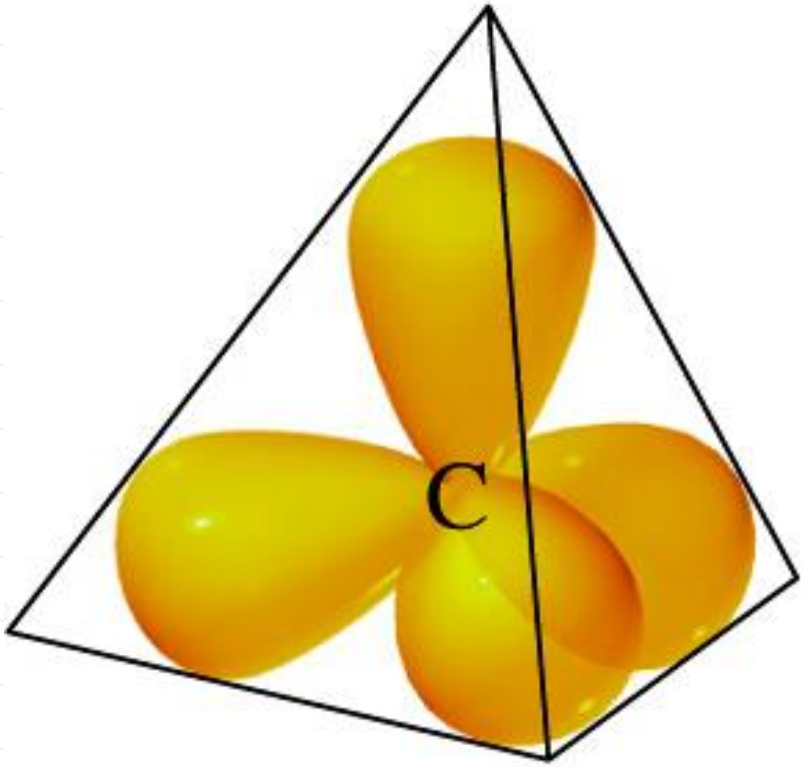
sp^3 sp^3 sp^3 sp^3

Formation of sp^3 Hybrid Orbitals



Hybridized Carbon Orbitals

- The four sp^3 orbitals are arranged in a tetrahedral shape.
- Each hybrid sp^3 orbital contains one electron and is available to bond with another atom.

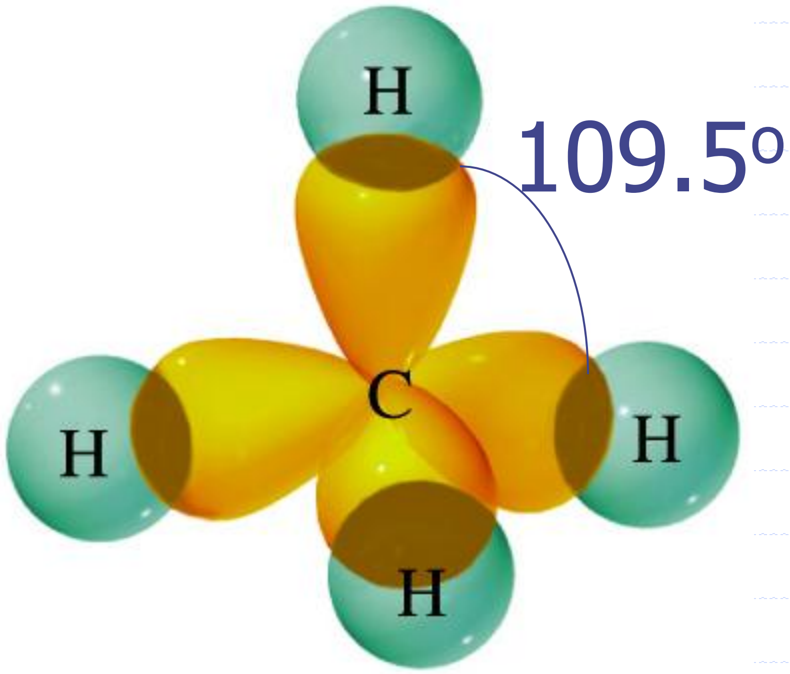


http://andromeda.rutgers.edu/~huskey/images/methane_

Methane

- Four hydrogen atoms, each having an s orbital, overlap with each of the sp^3 orbitals.

- Each of these bonds is called a **σ (sigma) bond.**



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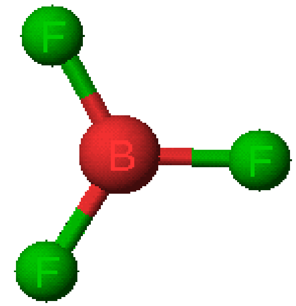
Hybridization of Orbitals Animation

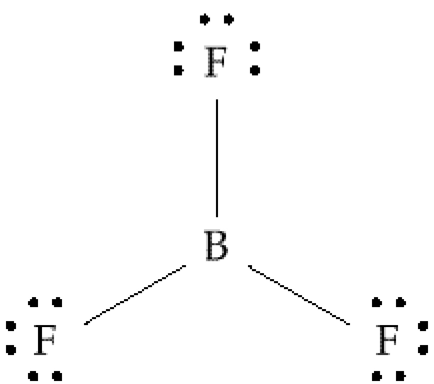
- http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/hybrv18.swf

Bonding in l

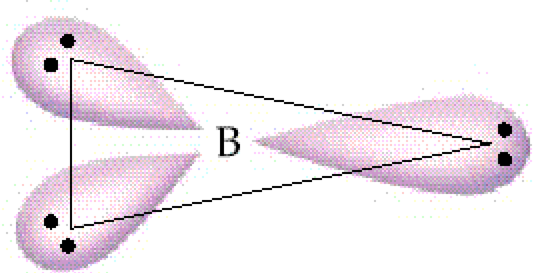


BF_3 - trigonal planar according to **VSEPR** Theory (incomplete octet exception)

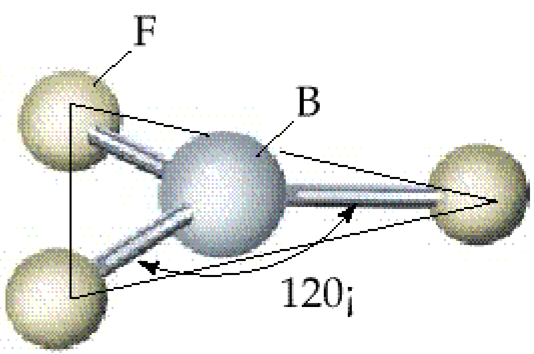
- How does Boron form 3 bonds 120º apart using a spherical s orbital and p orbitals that are 90º apart?



Lewis dot structure



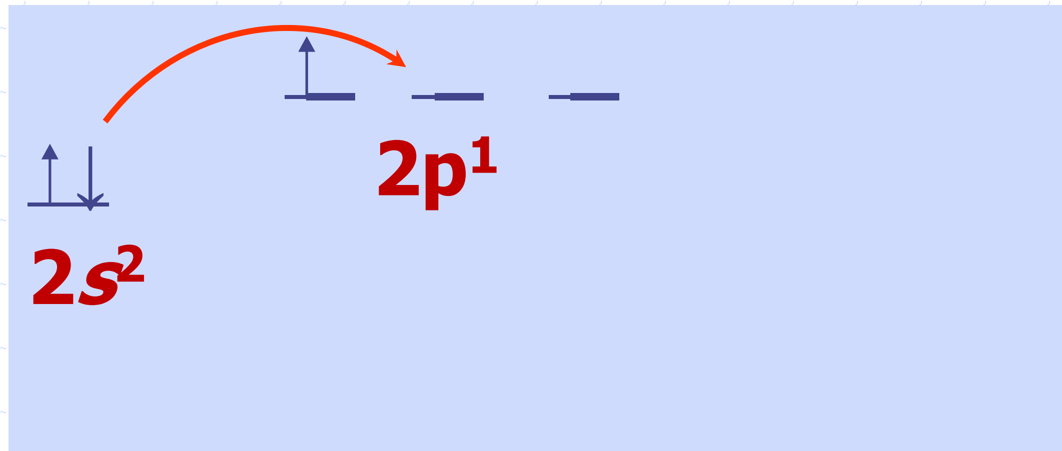
Electron-pair geometry



Molecular geometry

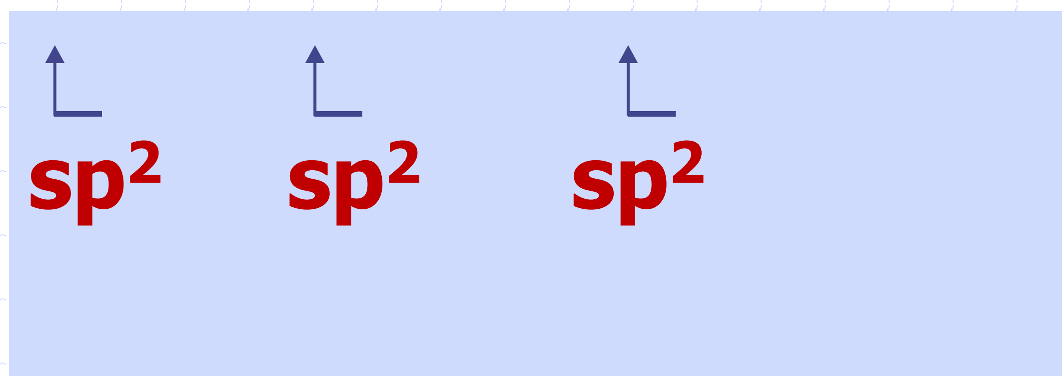
sp^2 Hybridization of B in BF_3

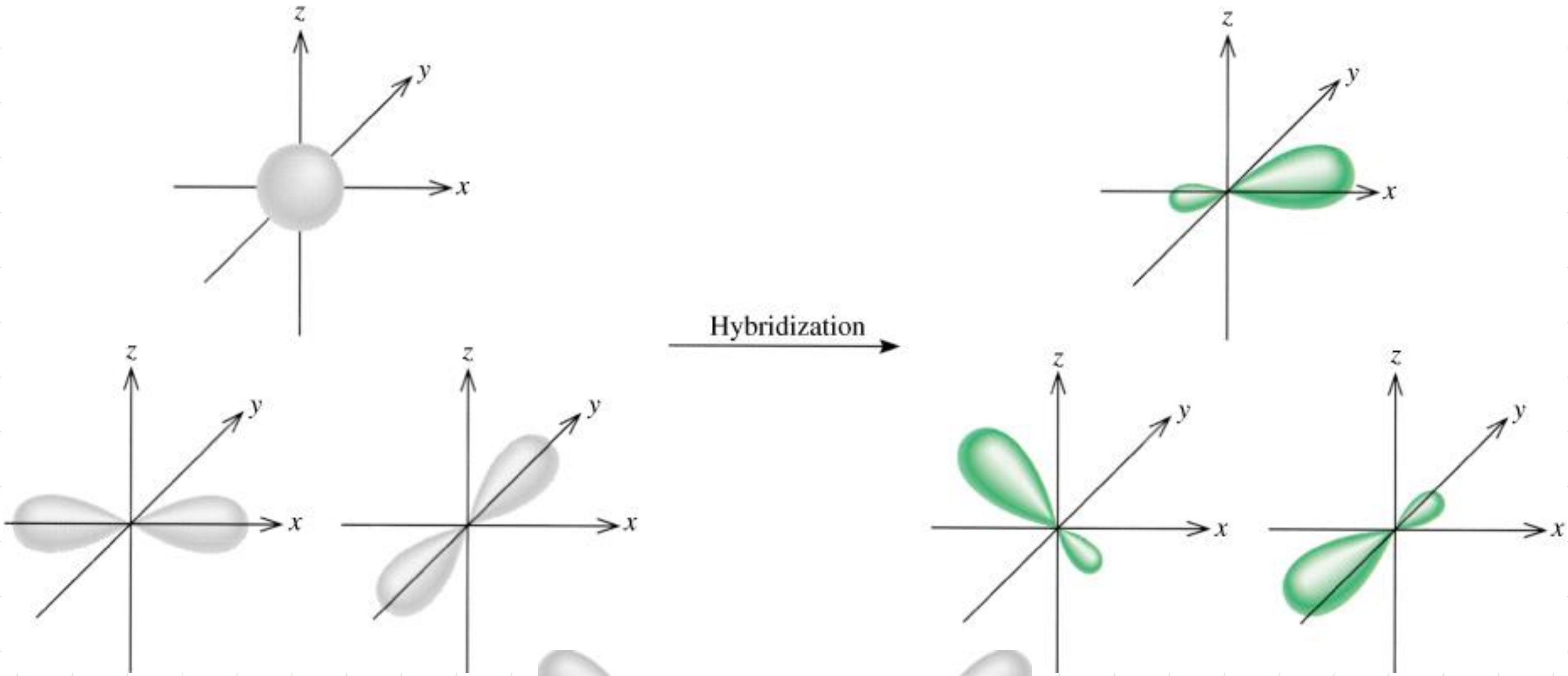
Unhybridized Boron

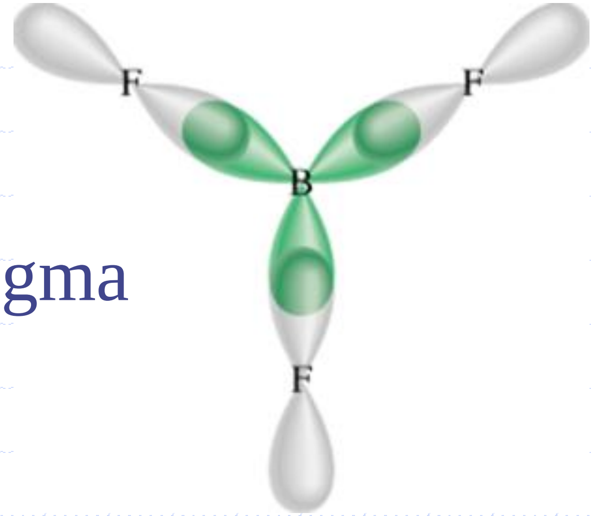


For BF_3, 3 hybrid orbitals are needed, so 3 atomic orbitals are required as follows: (s + p + p) = sp^2

hybridized Boron





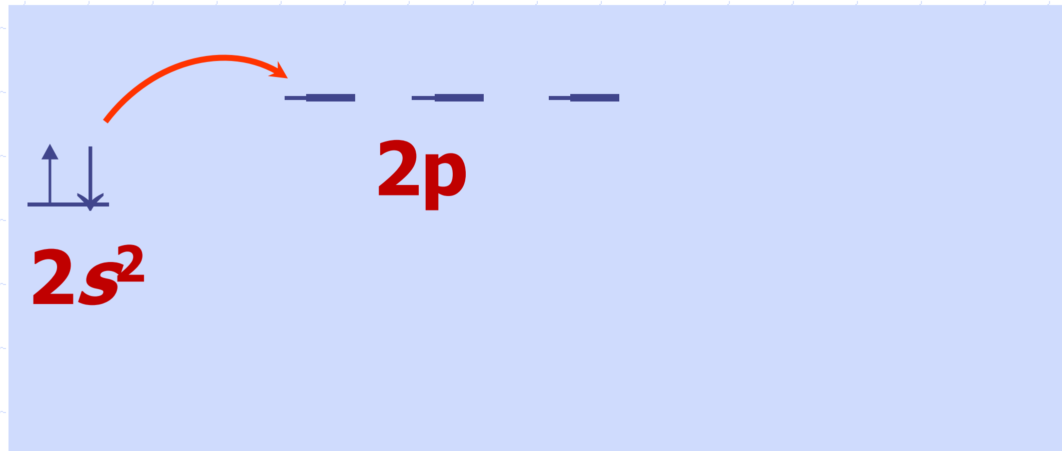


3 sp^2 orbitals

needed to form 3 sigma bonds

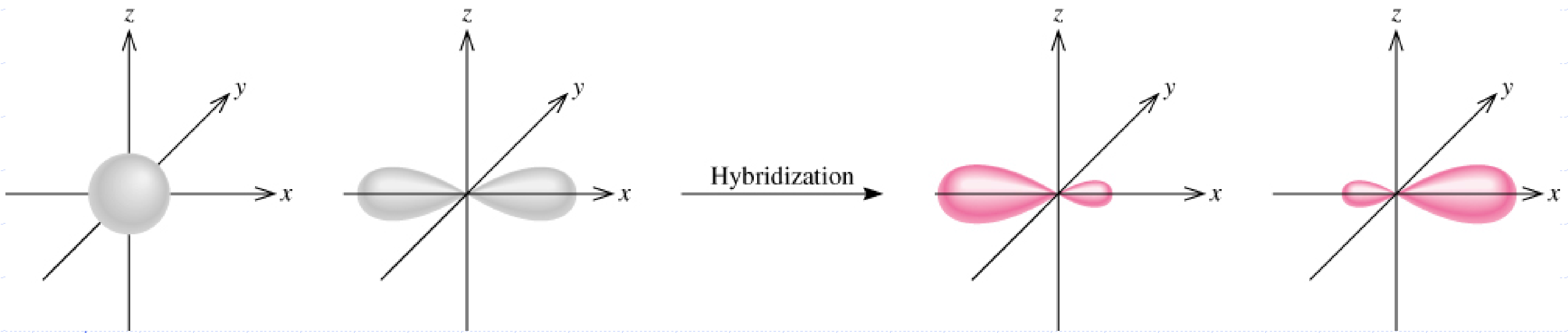
sp Hybridization of Be in $BeCl_2$

Unhybridized Be



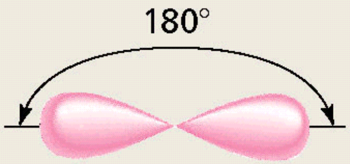
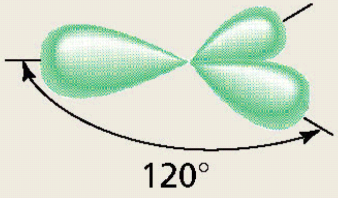
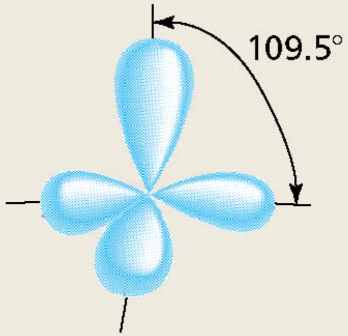
For $BeCl_2$, 2 hybrid orbitals are needed, so 2 atomic orbitals are required as follows: (s + p) = sp

hybridized Be


z
y
x
Hybridization


Cl
Be
Cl

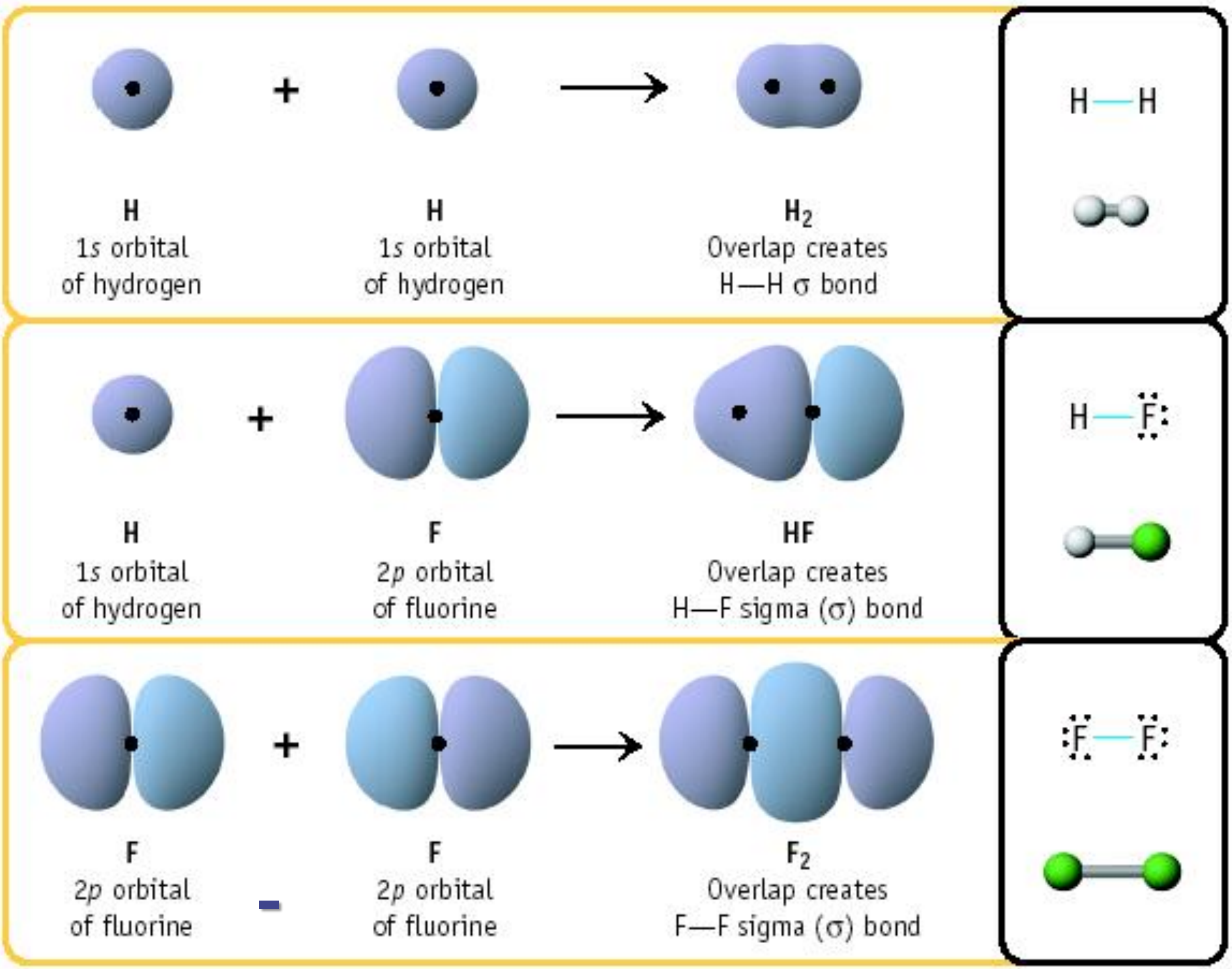
Table 10.4 Important Hybrid Orbitals and Their Shapes

Pure Atomic Orbitals of the Central Atom	Hybridization of the Central Atom	Number of Hybrid Orbitals	Shape of Hybrid Orbitals	Examples
s, p	*sp*	2	 Linear	$BeCl_2$
s, p, p	sp^2	3	 Planar	BF_3
s, p, p, p	sp^3	4	 Tetrahedral	CH_4, NH_4^+

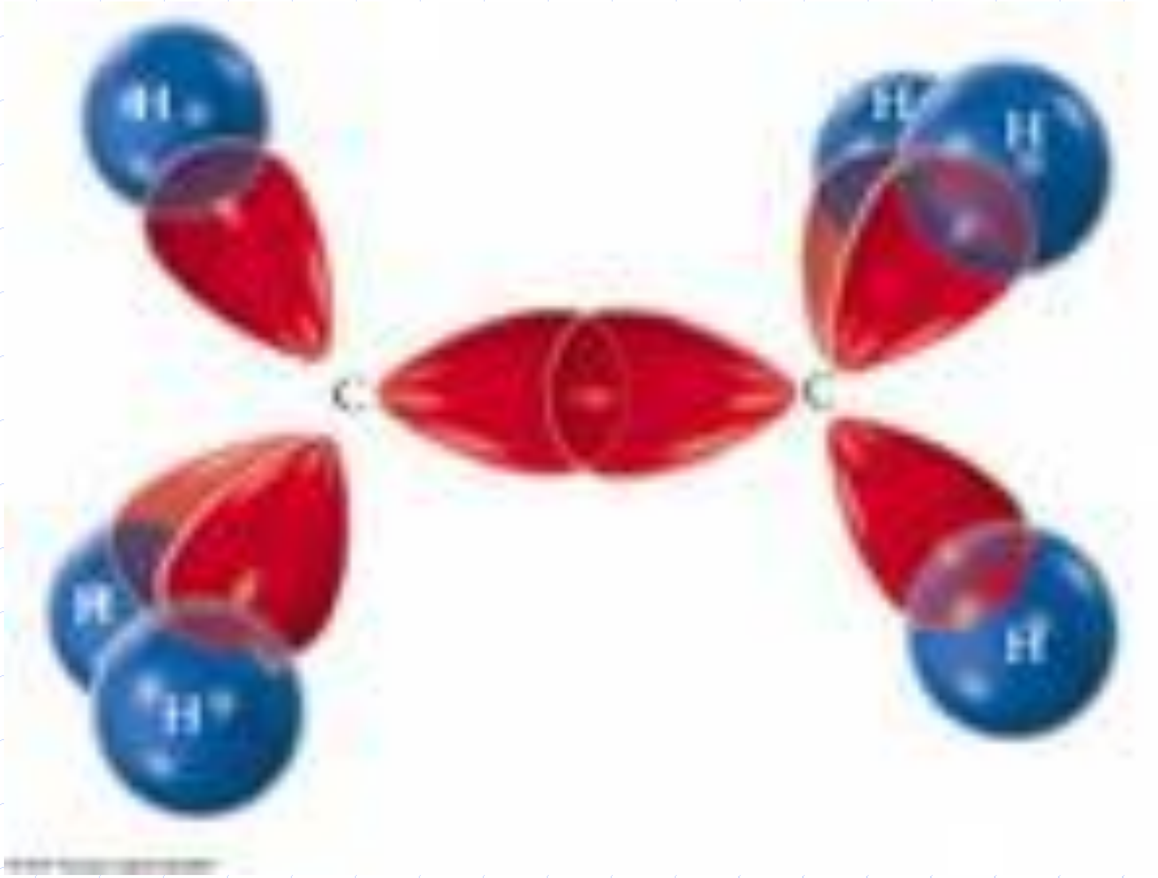
σ (sigma) bond

- A covalent bond formed by the overlap of orbitals along the bond axis end to end.
- A sigma bond can be formed by the overlap of:
  - s and p orbitals
  - two p orbitals
  - two s orbitals
  - two hybrid orbitals
  - an s orbital and a hybrid orbital

Sigma Bond Formation

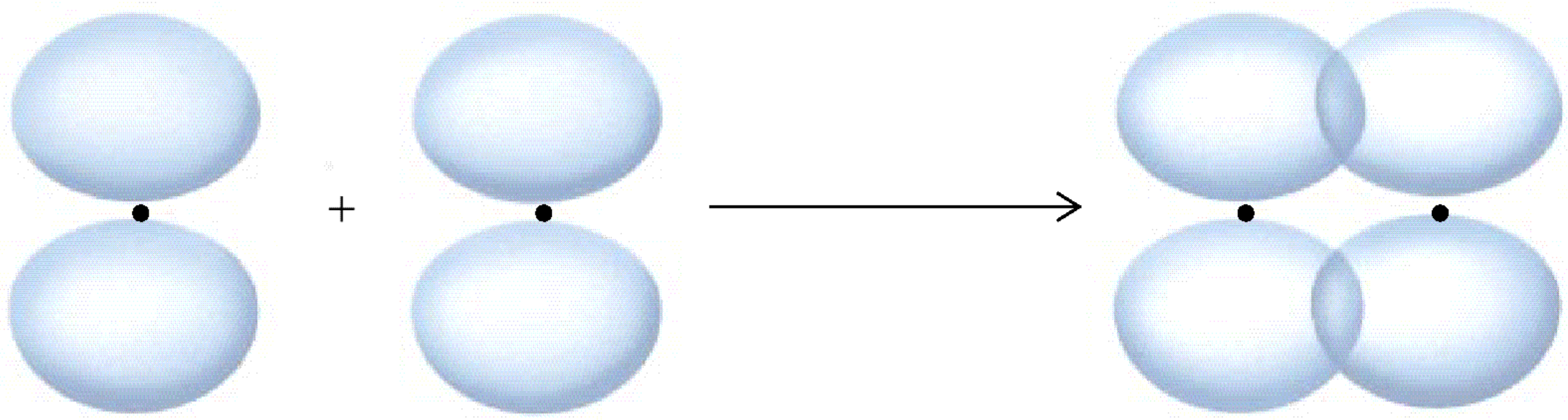


Ethane



π (pi bond)

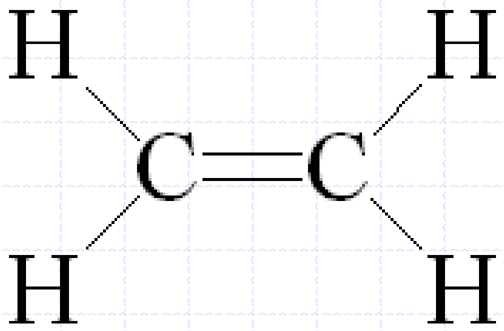
- A covalent bond formed by the parallel (side by side) overlap of two **p** orbitals.



p orbital + *p* orbital

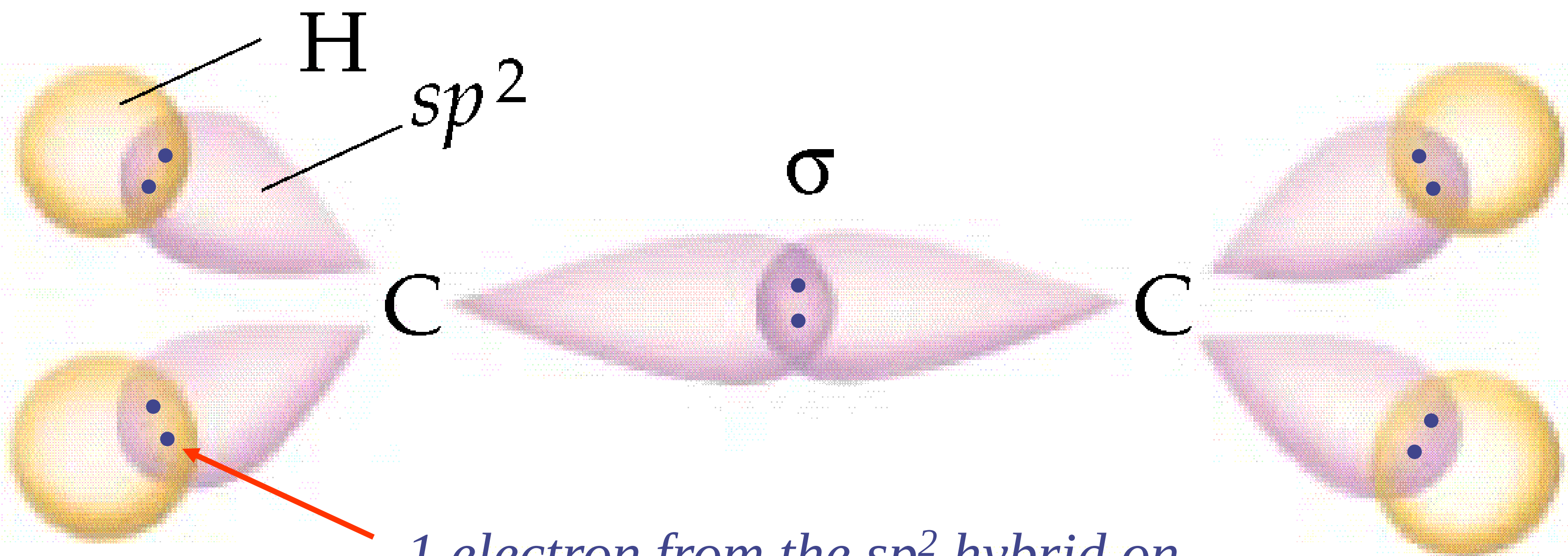
π bond

Ethylene (Ethene) C_2H_4



- Each carbon atom forms:
  - three hybrid sp^2 orbitals that lie on the same plane at 120^o
  - and a third p orbital that is lying perpendicular to the plane

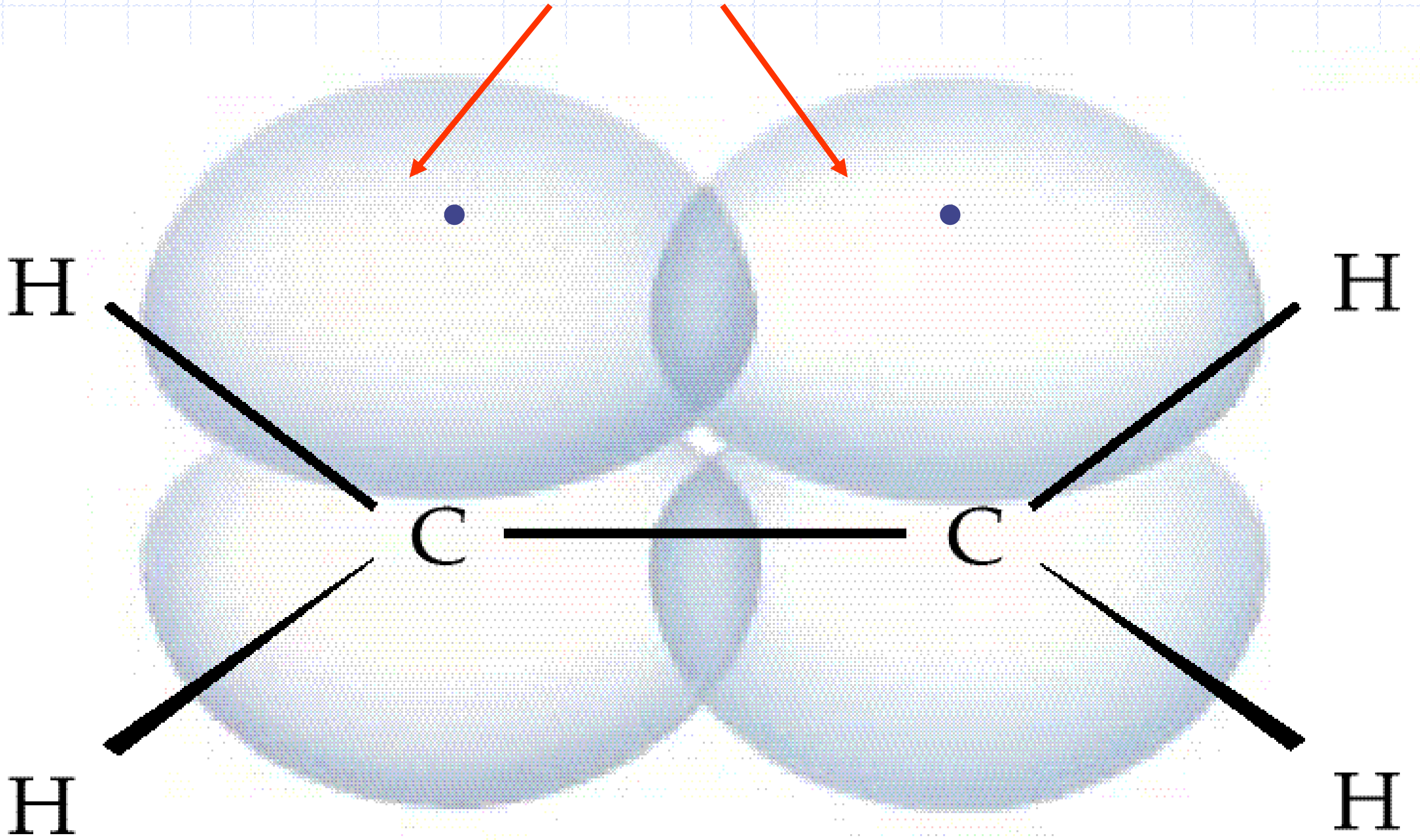
σ bond = end-to-end overlap of the sp^2 hybridized orbitals



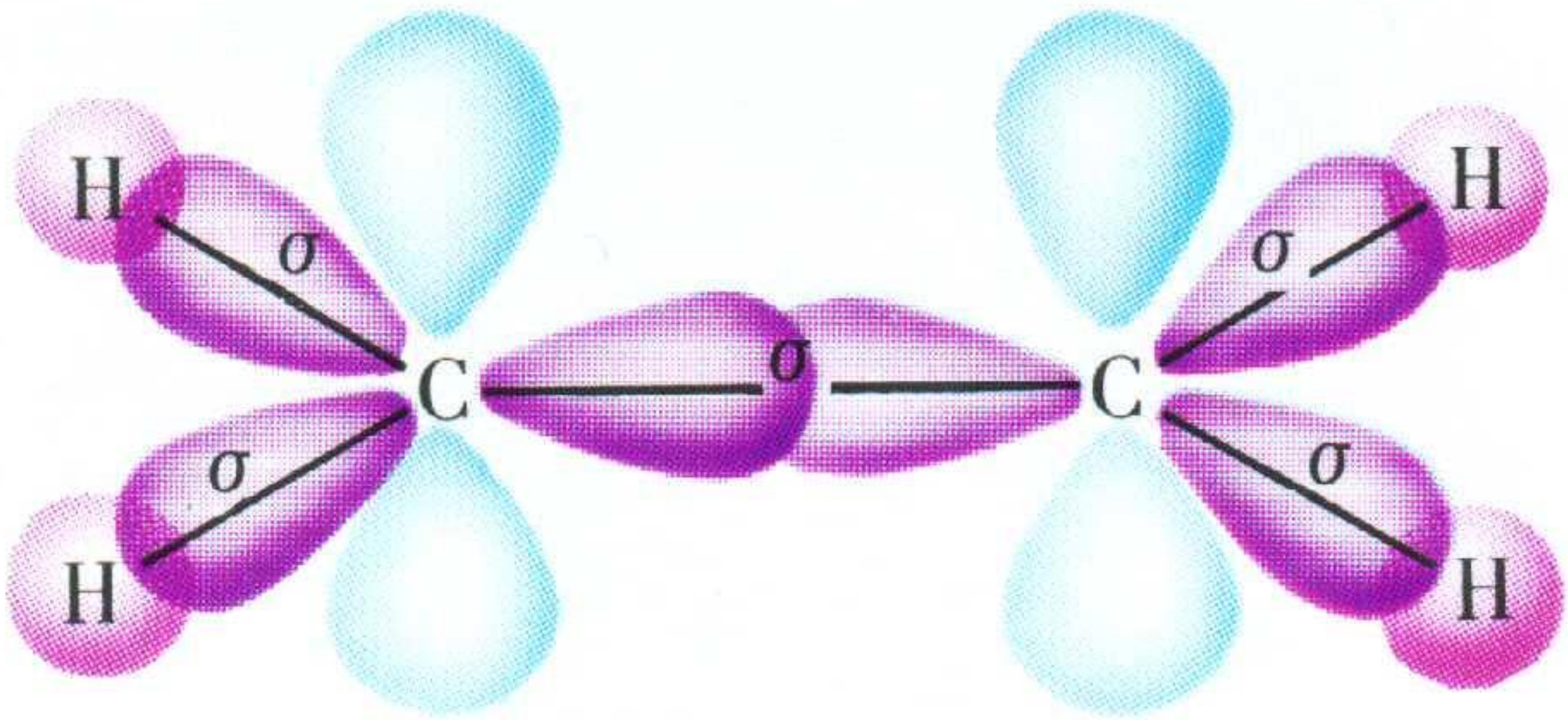
1 electron from the sp^2 hybrid on C, the other from the hydrogen 1s orbital

π bond = side-by-side overlap of the unhybridized p-orbitals

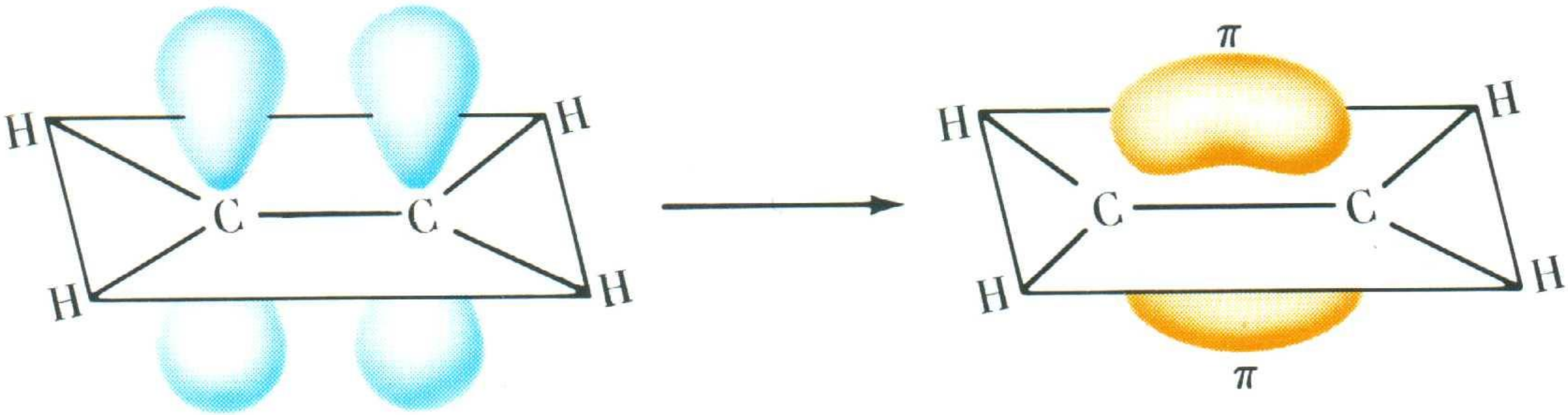
Electron from the unhybridized p-orbital on the C atom



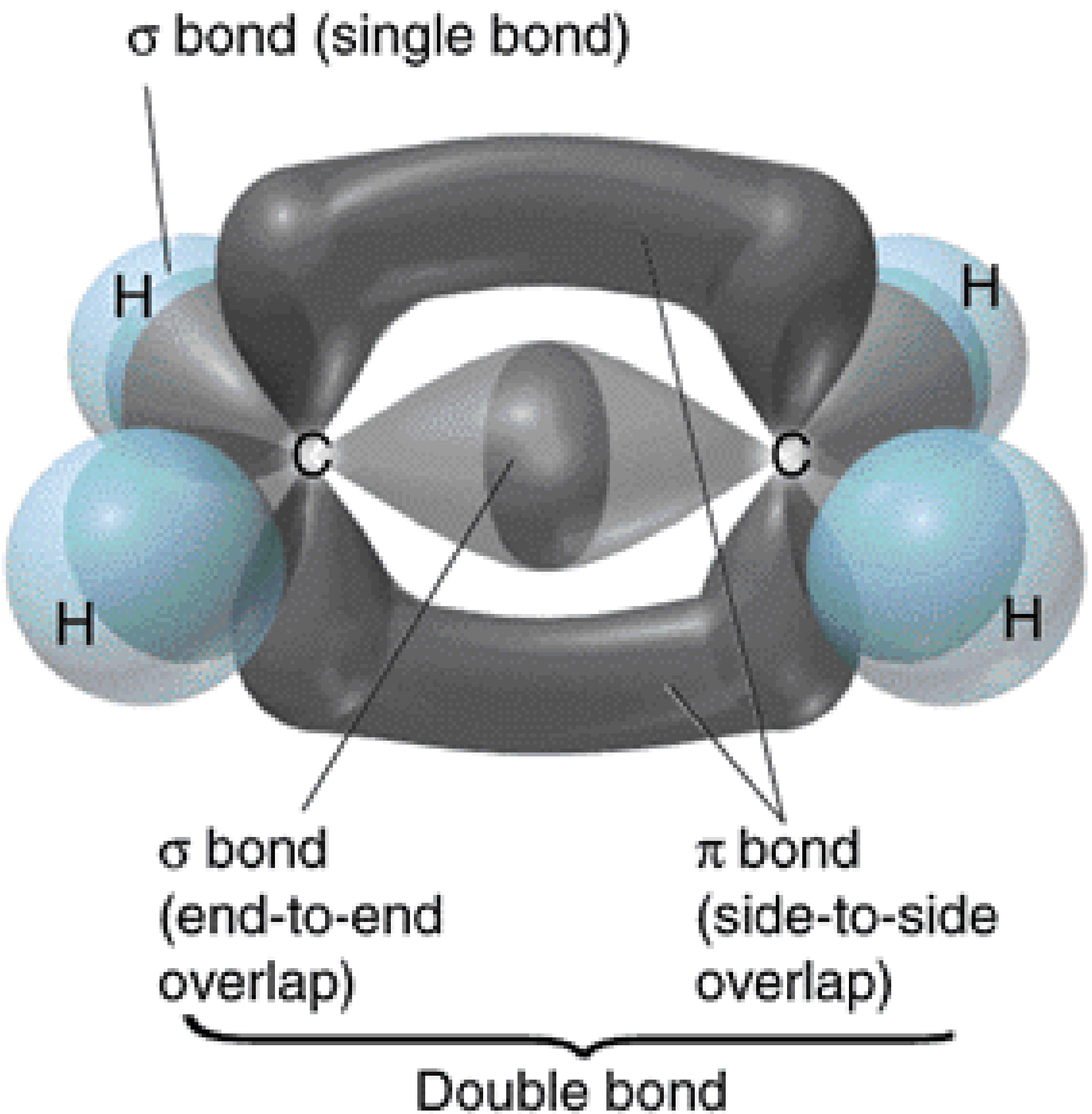
Sigma (σ) Bonding in Ethylene



Pi (π) Bonding in Ethylene

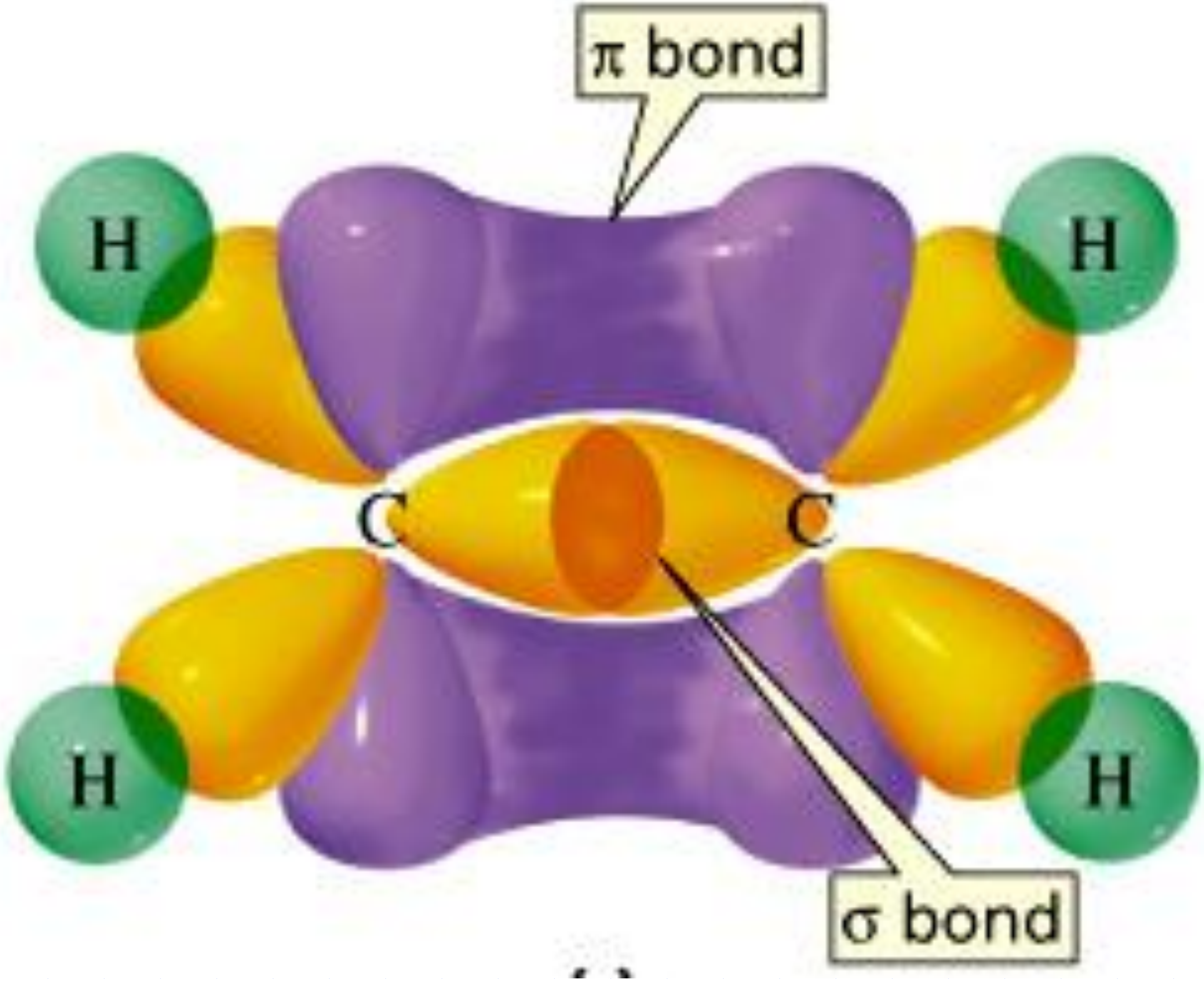


Ethylene (Ethene) C_2H_4



http://www.science.uwaterloo.ca/~cchieh/cact/fig/ethe

Ethylene (Ethene) C_2H_4



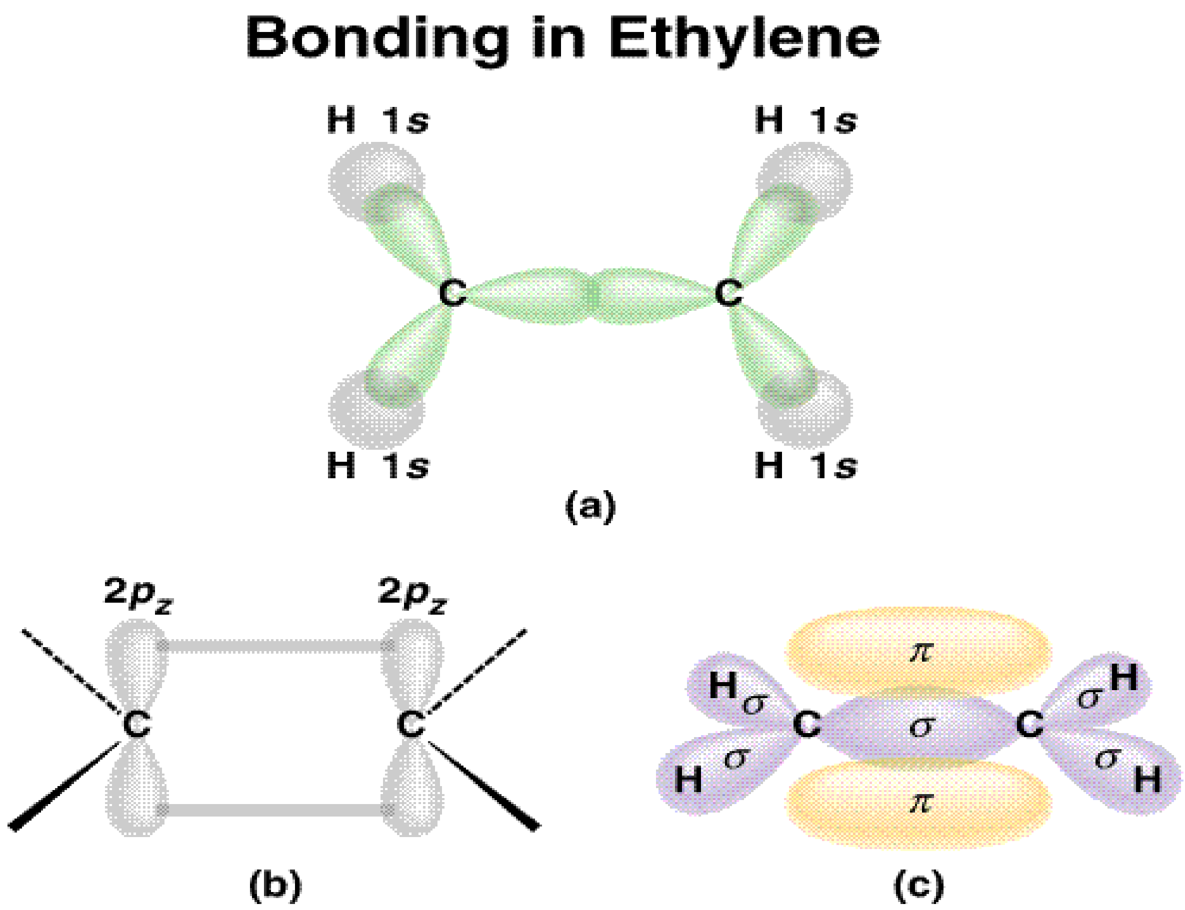
http://andromeda.rutgers.edu/~huskey/images/ethylene_bond

Ethene (Ethylene), C_2H_4

- The double bond between the two carbon atoms is made up of a sigma bond and a pi bond.
- The pi bond is made up of the parallel overlap of the p orbitals.
- The sigma bond is made up of the end to end overlap of the sp^2 orbitals.

Double Bond

- A double bond is made up of a sigma bond and a pi bond.



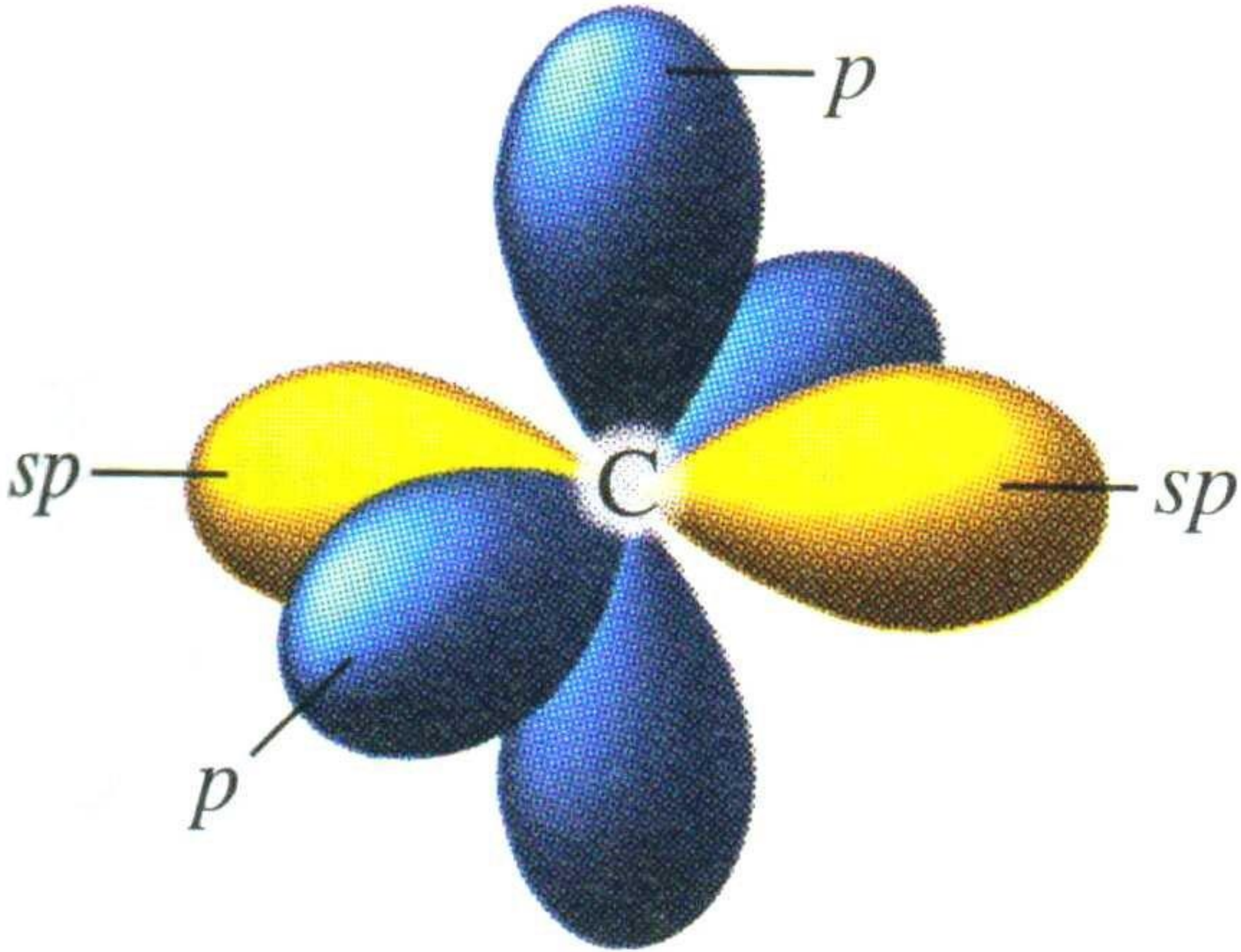
Acetylene (Ethyne), C_2H_2

$$H-C\equiv C-H$$

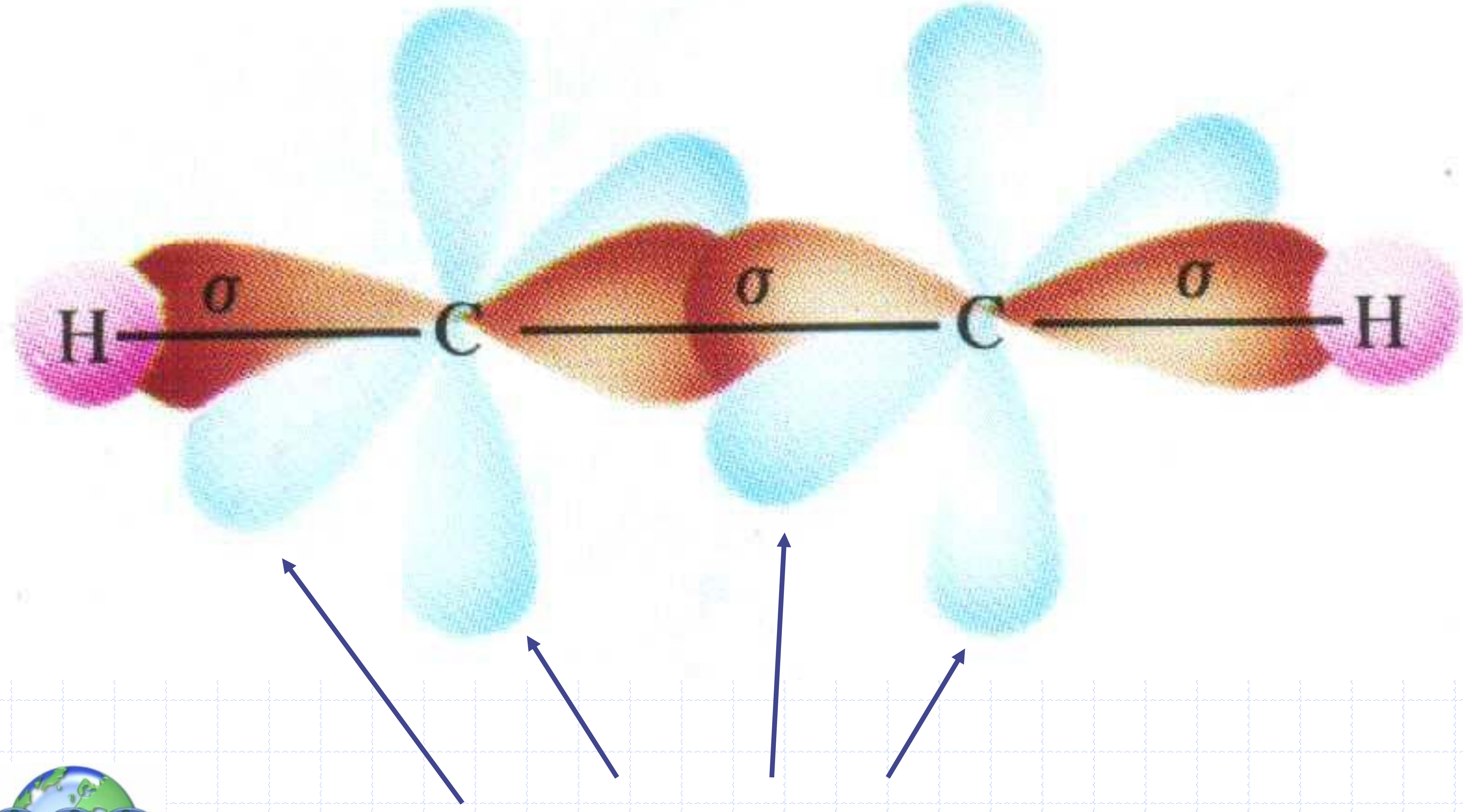
Acetylene has a triple bond between the two carbons.

- The carbon atoms form:
  - two hybrid sp orbitals
  - two p orbitals that overlap (2 π bonds)

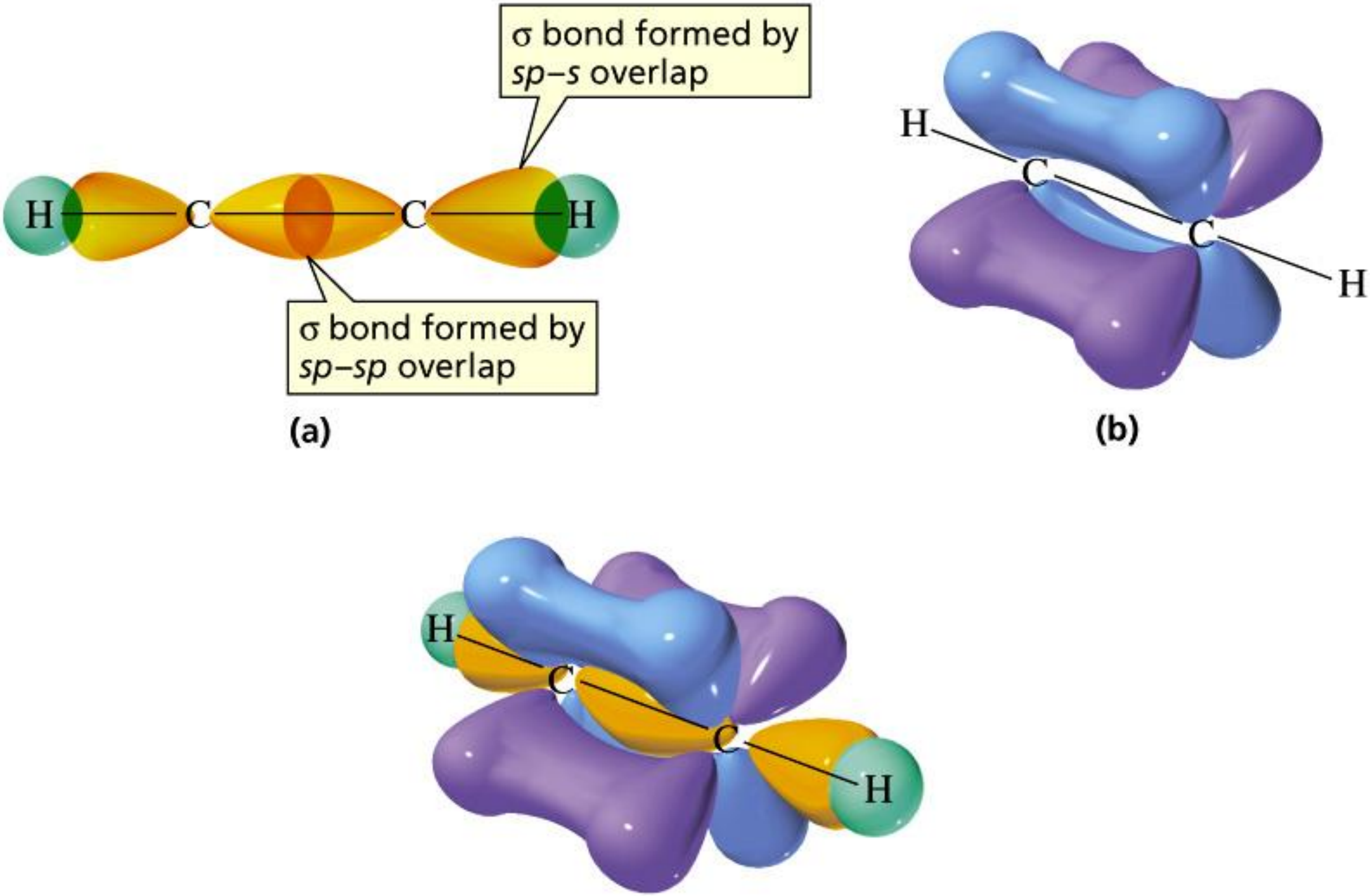
sp hybrids and unhybridized p-orbitals



Sigma (σ) Bonding in Acetylene



Acetylene (Ethyne), C_2H_2



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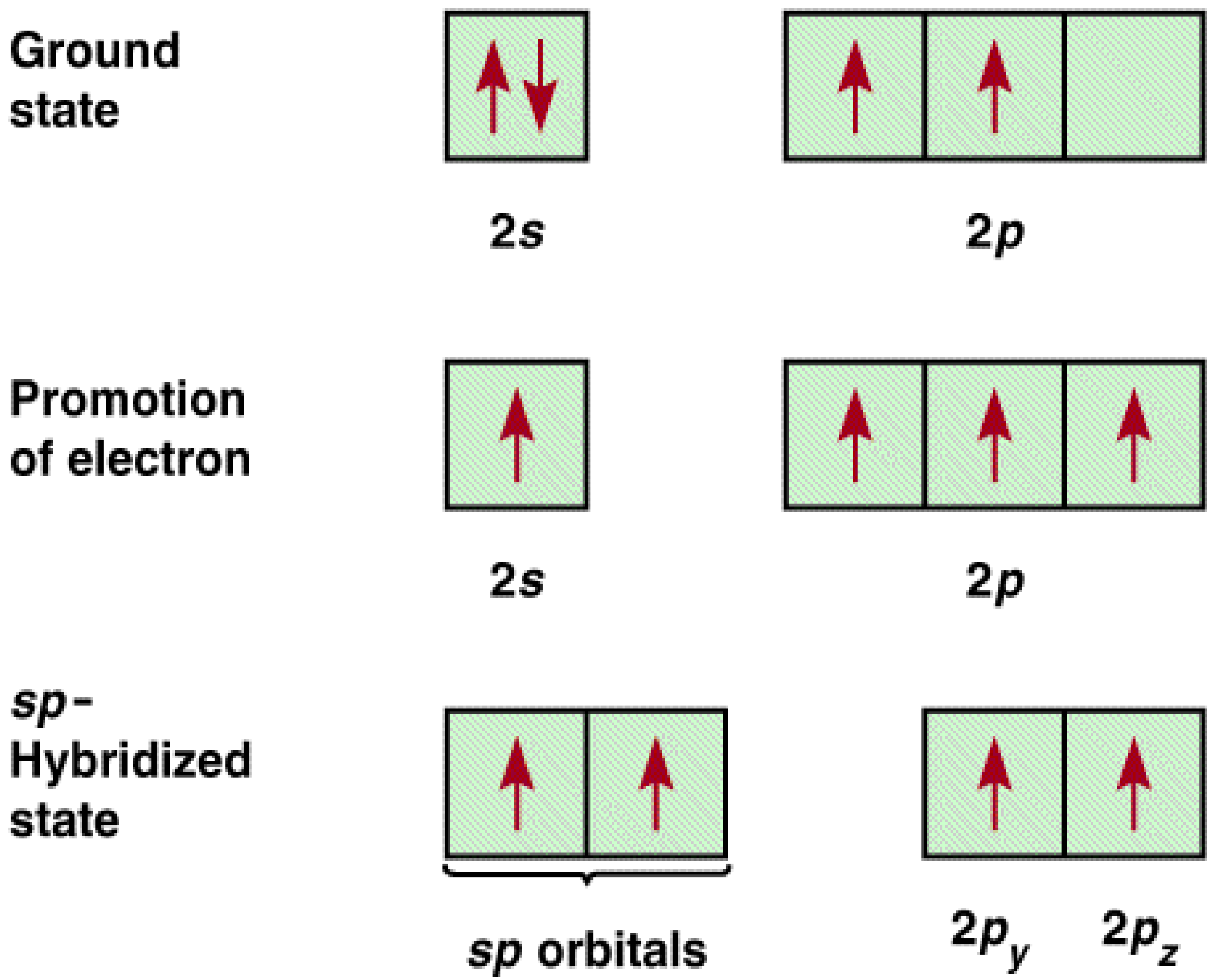
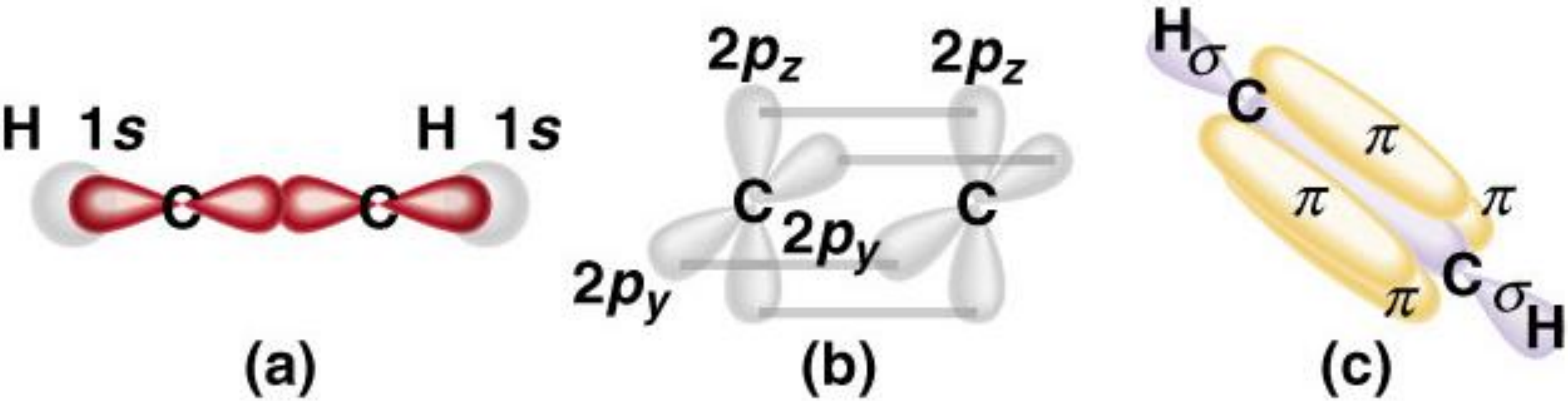
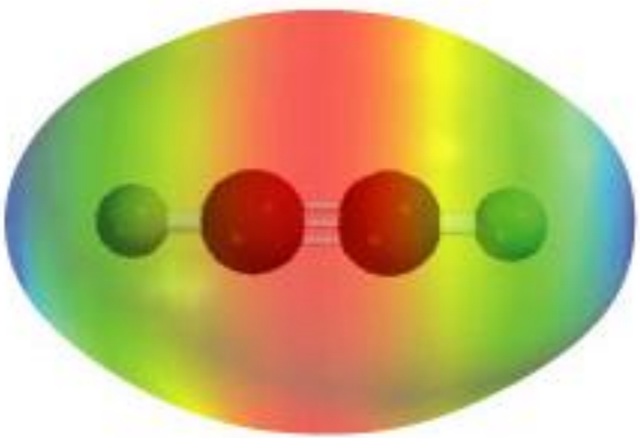
sp Hybridization of a Carbon Atom




H 1s
C
C
H 1s
(a)
2pz
2pz
C
C
2py
2py
(b)
H σ
C
π
π
π
π
C σ H
(c)

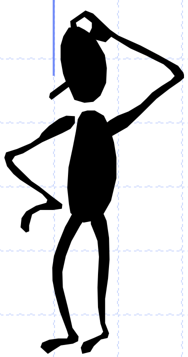


Triple Bond

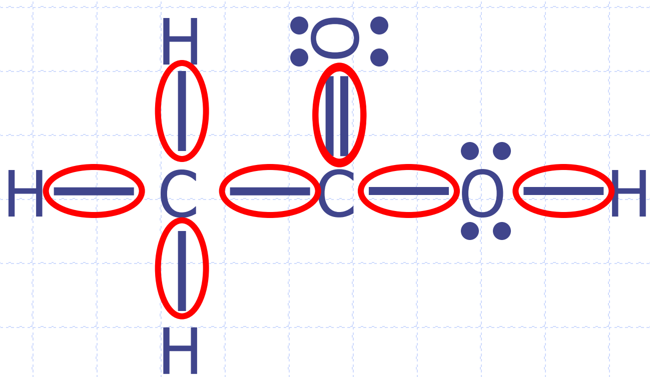
- Is made up of a sigma bond and two pi bonds.

Sigma (σ) and Pi Bonds (π)

- Single bond — 1 sigma bond
- Double bond — 1 sigma bond and 1 pi bond
- Triple bond — 1 sigma bond and 2 pi bonds



How many σ and π bonds are in the acetic acid (vinegar) molecule CH_3COOH?



σ bonds = 6 + 1 = 7

π bonds = 1

Gallery of Molecules

- http://webpages.dcu.ie/~pratta/jmgallery/JGALLERY.HTM
- Tutorial

http://www.wwnorton.com/college/chemistry/gilbert/tutorials/ch7.htm

Useful Websites

- http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/hybrv18.swf

- http://www-personal.une.edu.au/~sglover/CHEM110TopicAB/sld014.htm
- http://www.learnerstv.com/animation/animation.php?ani=52&cat=chemistry